THE UNIVERSITY OF TEXAS BULLETIN
No. 3014: April 8, 1930

MANUAL FOR WORKS OPERATORS IN WATER PURIFICATION AND SEWAGE DISPOSAL PLANTS

By

E. P. SCHOCH, Ph.D.
Professor of Physical Chemistry
Director of the Bureau of Industrial Chemistry

Bureau of Industrial Chemistry
Division of the Conservation and Development of the Natural Resources of Texas

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

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PREFATORY NOTE

This manual is intended to help the works operator to determine when he is treating a water—or sewage—with the proper amount of chemicals, or is operating in the proper manner. It is not designed to make him a chemist, or a bacteriologist; it is designed to enable him to do, *properly,* the thing he has to do—which is the proper *dosing* with chemicals for correct plant operation.

A number of tests and directions are the direct result of investigational work done at the University of Texas, and they are here presented, in this convenient form, for the first time. However, they have all been tested out in actual plant operation, and have been found dependable and serviceable.

Since the bacteriological examination is to be a *check* upon the plant operation, and since such examination can be made reliably only by specialists, no attempt has been made to give instruction on this subject in this manual.

Unless a plant operator is extensively trained to do bacteriological testing, it is better for all concerned that the water samples are sent out to a specialist to be tested. Directions issued by the State Board of Health for taking and shipping samples are included here—also directions for interpreting the bacteriological results. The State Health Department does not undertake to make a continuous series of tests, and samples should not generally be sent very far, but a medical clinic or pathological laboratory can usually be found near by which will undertake to do the work.

Whenever a water operator desires to learn to make the tests in this manual he can get the necessary instruction free of charge at the University of Texas, Bureau of Industrial Chemistry. Arrangement for a suitable date to receive this instruction should be made by mail before hand.

The University of Texas—through its Bureau of Industrial Chemistry—gives free advice on all Texas waters to be used for domestic or industrial purposes; it will examine

them to determine whether or not they are fit for drinking, for boiler use, or for irrigation, and if a water requires treatment to render it fit for a particular use the Bureau will give the necessary directions for such treatment. In order to secure such aid, any citizen need simply write a letter stating (1) the purpose for which the water is to be used, (2) the source of the water, and if from a well, the location and depth of the latter. Also send one gallon of the water to be examined.

Mineral waters are not usable for industrial purposes—hence will not be examined by this Bureau.

Address: Bureau of Industrial Chemistry,
The University of Texas,
Austin, Texas

MANUAL FOR WORKS OPERATORS IN WATER PURIFICATION AND SEWAGE DISPOSAL PLANTS

1. THE FUNDAMENTAL UNIT FOR THE WEIGHTS OF CHEMICALS:—THE GRAM-EQUIVALENT.

All materials are made up of distinct pieces called molecules, and the latter are made up of atoms, or distinct pieces of elements. Thus water is made up of pieces of hydrogen and oxygen as indicated by the symbol HOH; hydrochloric acid is made up of hydrogen and chlorine, as expressed by HCl; calcium carbonate is made up of calcium, carbon, and oxygen as expressed by $CaCO_3$.

The theoretical way of measuring chemical substances is to *count* the number of molecules. To carry this out *practically* we count them in bunches. The actual number of molecules present in a bunch of the simplest molecules is very large. It is "6 followed by twenty-three naughts," and such a bunch is called "one gram-equivalent."

The weight, in grams, of a gram-equivalent of each substance is known, and can be found in any chemist's handbook. A few are given here:

1 gram-equivalent of salt weighs 58.5 grams
1 gram-equivalent of calcium carbonate weighs 50 grams
1 gram-equivalent of quicklime weighs 28 grams
1 gram-equivalent of hydrated lime weighs 37 grams
1 gram-equivalent of filter alum weighs 111 grams
1 gram-equivalent of iron sulphate weighs 139 grams.

By means of the weights, we can easily weigh out such a "bunch" of molecules of any chemical.

2. SIMPLE METHOD OF PREPARING NORMAL SOLUTIONS, AND THE PREPARATION OF N/20 ACID SOLUTION AND OF STANDARD LIME SOLUTION.

When solutions of some particular, and exact, strength are to be prepared, this is done by putting 1 gram-equivalent of that chemical into a flask of definite capacity, say 1 or 2 liters, and filling it up with distilled water. When 1

gram-equivalent is thus put into 1 liter of volume, the resulting solution is said to be *normal*—written N/1; when it is put into 10 liters,—the solution is said to be tenth-normal—written N/10; etc.

Such solutions are used in testing waters to adjust the proper dosage of chemicals used in plant operation. They are prepared most conveniently by means of sealed glass tubes called "Fixanal Tubes"—which contain exactly 1/10 gram-equivalent of any particular substance—for instance, of hydrochloric acid. They are sold by Pfaltz and Bauer, Inc., 300 Pearl Street, New York, price 90 cents. These "Fixanal" tubes are made so that their contents are easily *washed* into a volumetrical flask. "Fixanal" tubes with larger amounts in them also are obtainable.

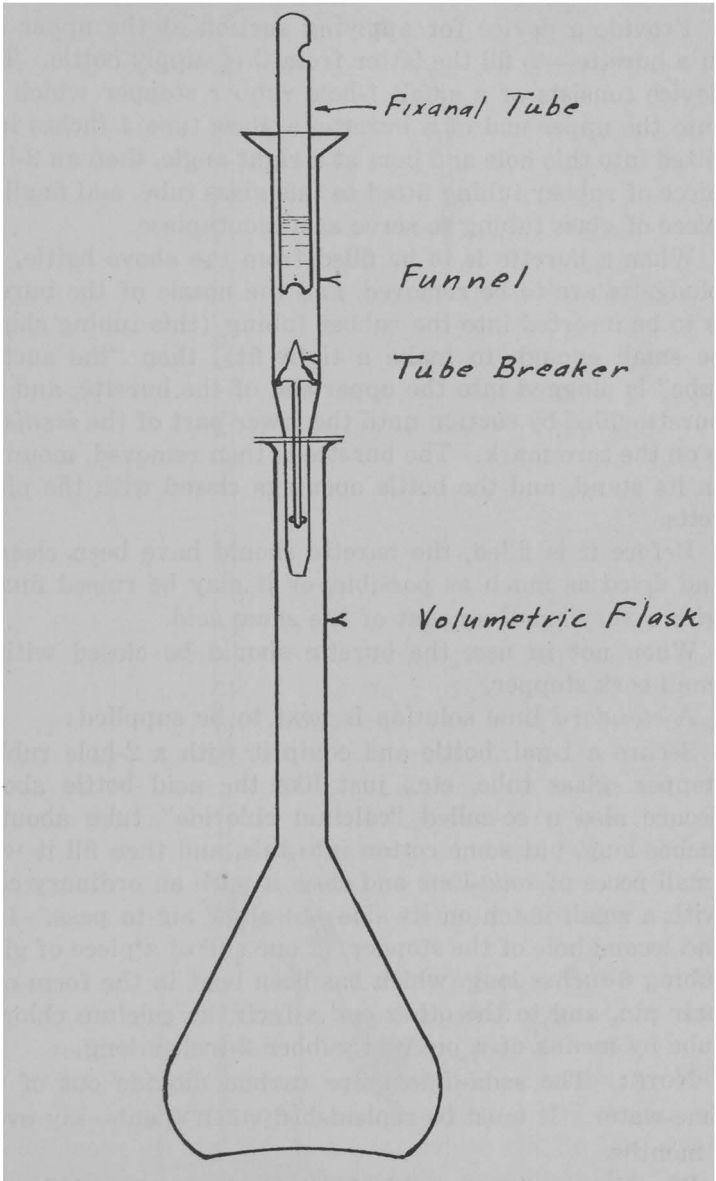
Since twentieth-normal (or N/20) hydrochloric acid is needed in this work, the preparation of this solution will be described.

Note: The equipment needed to do the work in this manual is listed under Article 19 at the end.

Secure a 2-liter volumetric flask, rinse it out with distilled water, put the funnel with the "tube-breaker" on the flask, insert a "1/10 gram-equ. HCl" Fixanal tube into this funnel, thus puncturing its lower end; then puncture the Fixanal tube near the top at the *indented* place, and with the aid of a chemist's wash bottle, wash all traces of the acid from the tube and funnel *into* the flask below.

Remove the funnel, add water to the mark on the neck of the flask, close it with a rubber stopper or a glass stopper, and mix the contents by inverting the bottle repeatedly and shaking it.

Next, secure a 3 or 4 qt. bottle fitted with a 2-hole rubber stopper; through one of these holes fit a glass tube extending from the bottom of the bottle to 1 inch above the stopper, and fit a piece of rubber tuding, 2 inches long, over this upper end of the glass tube. Insert pludgetts of wood into the end of this rubber tube and also into the second hole of the rubber stopper. Clean this bottle, then rinse it with distilled water, and also with a little of the acid to be put into it, and finally put this acid solution into the bottle to have the bottle and its equipment ready for use. Label it: "N/20 HCl."



Method of Preparing Volumetric Solutions with use of Fixanal Tube

Provide a device for applying suction at the upper end of a burette—to fill the latter from this supply bottle. This device consists of a small 1-hole rubber stopper which fits into the upper end of a burette, a glass tube 4 inches long fitted into this hole and bent at a right angle, then an 8-inch piece of rubber tubing fitted to this glass tube, and finally a piece of glass tubing to serve as a mouthpiece.

When a burette is to be filled from the above bottle, the pludgetts are to be removed, and the nozzle of the burette is to be inserted into the rubber tubing (this tubing should be small enough to make a tight fit), then "the suction tube" is plugged into the upper end of the burette, and the burette filled by suction until the lower part of the *meniscus* is on the zero mark. The burette is then removed, mounted on its stand, and the bottle openings closed with the pludgetts.

Before it is filled, the burette should have been cleaned and dried as much as possible, or it may be rinsed finally with a very small amount of the same acid.

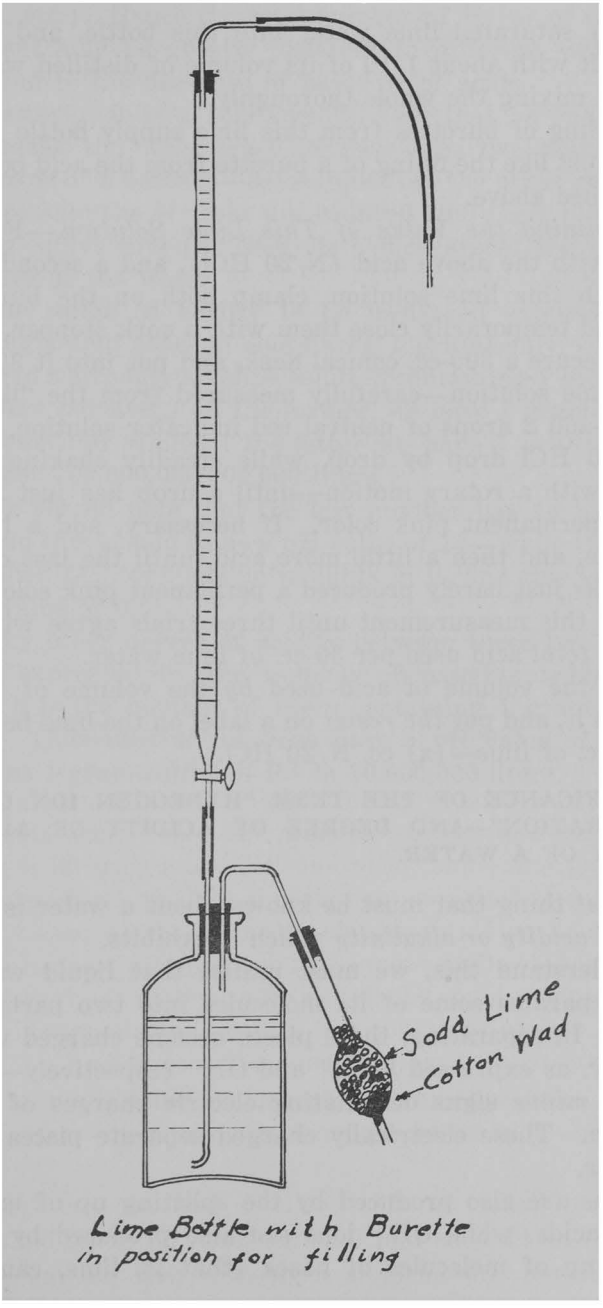
When not in use, the burette should be closed with a small cork stopper.

A *standard* lime solution is next to be supplied:

Secure a 1-gal. bottle and equip it with a 2-hole rubber stopper, glass tube, etc., just like the acid bottle above. Secure also a so-called "calcium chloride" tube about 8 inches long, put some cotton into this, and then fill it with small peces of *soda-lime* and close it with an ordinary cork with a small notch on its side—to allow air to pass. Into the second hole of the stopper, fit one end of a piece of glass tubing 6-inches long, which has been bent in the form of a hair pin, and to the other end attach the calcium chloride tube by means of a piece of rubber 2-inches long.

NOTE: The soda-lime keeps carbon dioxide out of the lime-water. It must be replenished when spent—say every 6 months.

The lime water for this bottle is best secured from a druggist who is to be told that it should be clear, but only 9/10 saturated; the latter is secured by first putting clear



Lime Bottle with Burette in position for filling

(filtered) saturated lime water into this bottle, and then diluting it with about 1/10 of its volume of distilled water, and then mixing the whole thoroughly.

The filling of burettes from this lime supply bottle is to be done just like the filling of a burette from the acid bottle, as described above.

Determining the Value of This Lime Solution.—Fill a burette with the above acid (N/20 HCl), and a second burette with this lime solution, clamp both on the burette stand, and temporarily close them with a cork stopper.

Then secure a 300-cc. conical flask, and put into it 30 cc. of this lime solution—carefully measured from the "lime" burette—add 2 drops of neutral red indicator solution, and add N/20 HCl drop by drop, while steadily shaking the mixture with a rotary motion—until a drop has just produced a permanent pink color. If necessary, add a little more lime, and then a little more acid, until the last drop of acid has just barely produced a permanent pink color.

Repeat this measurement until three trials agree within 0.2 cc. of *total* acid used per 30 cc. of lime water.

Divide the volume of acid used *by* the volume of lime used with it, and put *the result* on a label on the lime bottle, thus: 1 cc. of lime=(x) cc. N/20 HCl.

3. SIGNIFICANCE OF THE TERM "HYDROGEN ION CONCENTRATION"—AND DEGREE OF ACIDITY OR ALKALINITY OF A WATER.

The *first* thing that must be known about a water is the *degree of acidity or alkalinity* which it exhibits.

To understand this, we must realize that liquid water always separates some of its molecules into two parts, *H* and *OH*. In separating, these pieces become charged with electricity, as expressed by H^+ and OH^- respectively—the *plus* and *minus* signs designating electric charges of the same sign. These electrically charged separate pieces are called *ions*.

H^+ ions are also produced by the splitting up of molecules of acids, while OH^- ions are also produced by the splitting up of molecules of bases (that is, lime, caustic

soda, etc.). Hence the total number of H^+ or of OH^- ions present may be greatly different in different waters—according to the presence of bases or of acids.

However, it is a fundamental fact that as one of these increases, the other must decrease—the two changing like the pans of a balance—as one goes up, the other goes down. Hence only the H^+ ions are counted, and their number (in gram-equivalents per liter) is a measure of the degree of acidity of the water.

The range of acidity to be measured extends from a strongly acid solution containing 1 gram-equiv. of H^+ per liter to a strongly alkaline solution containing 1 gram-equiv. of OH^- per liter. In the former, we have 1 gram-equiv. of H^+ per liter while in the latter we have 1 gram-equiv. of H^+ per 100,000,000,000,000 liters.

We should note that the last number has 14 naughts in it, and this is said to be a pH value of 14—while the former number (1 liter) has no naughts in it, and this is called a pH value of 0.

Any other degree of acidity between these two values is also expressed by the number of naughts behind the 1 which is the number of liters containing 1 gram-equiv. of H^+. Thus *neutral* solutions have a pH value of 7, which means 1 gram-equiv. of H^+ in 10,000,000 liters.

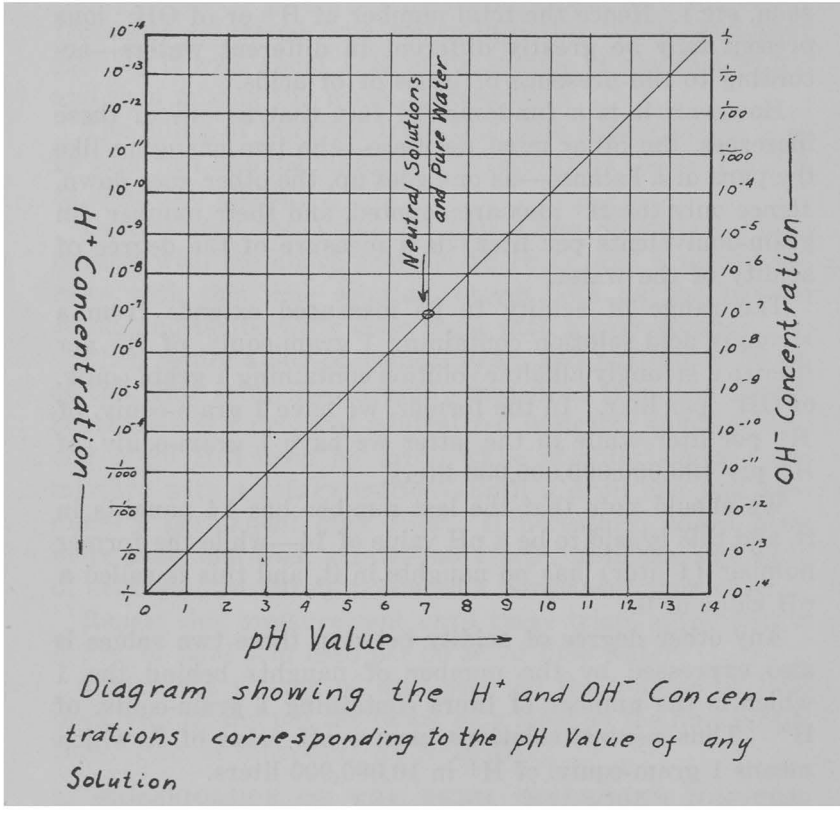


Diagram showing the H^+ and OH^- Concentrations corresponding to the pH Value of any Solution

The above diagram may be used as follows:

In order to ascertain the H^+ and the OH^- concentrations of a solution which has a pH value of 4, we locate the point where the vertical line from 4 in the bottom intersects the diagonal line, and then we look at the ends of this horizontal line through this point: the left end indicates the H^+ concentration (10^{-4}), and the right end the OH^- concentration, (10^{-10}).

The diagram also shows that the H^+ concentration *decreases* as the pH values increase, and that the OH^- concentration increases correspondingly so that the product of these two values is always the same. In this case we have:

10^{-4} times 10^{-10} equals 10^{-14}.

4. METHOD OF MEASURING pH VALUES.

pH values are measured by a series of dyes which *turn* color at certain known pH values. Many different dyes can be used,—the following series is merely one for illustration. The following table presents the pH range in which each dye gradually changes color, together with the color it shows with lesser pH values (acid color!) or with greater pH values (basic color!) than this turning point.

Name of Dye	*Acid Color*	*pH of turning point*	*Basic Color*
1. Methyl Orange	Red	2.9— 4.0	Yellow
2. Brom phenol blue	Yellow	3.0— 4.6	Blue
3. Methyl red	Red	4.2— 6.4	Yellow
4. Brom cresol purple	Yellow	5.2— 6.8	Purple
5. Brom thymol blue	Yellow	6.0— 7.6	Blue
6. Neutral red	Red	6.8— 8.0	Yellow
7. Cresol red	Yellow	7.2— 8.8	Red
8. Thymol blue	Yellow	8.0— 9.6	Blue
9. Phenolphthalein	Colorless	8.4—10.0	Pink
10. Thymolphthalein	Colorless	9.3—10.5	Blue

Thymolphthalein in boiling solutions *begins* to turn blue at 10.23.

To determine the pH value of a water, add 2 or 3 drops of the various dye solutions to different small portions (about 10 cc.) of a water—in test tubes, note the color changes and also the depths of colors, and with the data in the above list decide what is the approximate pH value of the water. This should be learned by trial with several waters of known pH.

A "closer" determination of the pH value can then be made by the "drop ratio" method, directions for which procedure will be found on p. 39 of "Standard Methods of Water Analysis" published by the American Public Health Association, 370 Seventh Avenue, New York, N.Y. However, this is seldom necessary.

While solutions of these dyes can be prepared in water—with the aid of definite amounts of an alkali—yet it is generally more convenient to dissolve them in 50% alcohol. Denatured alcohol may be used.

In general 2 grams of dye are dissolved per liter of 50% alcohol,—but with the following dyes, the amounts per liter are: Neutral red, 1/4 gram; methylorange, 1 gram; thymolphthalein, 4 grams.

5. CHOICE OF MATERIALS AND OF METHOD OF TREATMENT FOR PURIFYING A WATER.

The proper choice of materials, and of the method of treating a water requires a chemical examination of the water: all this should be done before the plant is designed —and should be done by a competent chemical engineer. Hence the following directions along this line are here given merely for general information. They show the works operator *why* he should make the different tests given below.

The first thing to be done in selecting the proper treatment of a water is to determine the pH value which the turbidity requires for its removal. This may be as low as 5.5—as in Baltimore where a light, colored impurity must be removed, or as high as 9.5 which is required to remove the hydrated silica in some western waters—and even above 10, as is the case when waters are to be softened.

When this pH value is below 8, only alum can be used as a coagulant because iron sulphate does not *floc* out below 7, and makes only a poor floc below 8; but when—as is frequently the case, the turbidity may be removed at any pH above 8, then we have the choice of using either alum or iron sulphate. Furthermore we then also have the possibility of *softening* the water—hence of operating at pH=10 or above, and with these latter pH values iron sulphate produces a better settling floc than alum.

Aluminum sulphate—$Al_2(SO_4)_3$ 18 H_2O—commonly designated as "filter alum," can be used over the *whole range* of pH values—that is, it will combine with suspended matter at any pH value from 5.5 to 10. However, when suspended matter is absent, or when the amount of alum exceeds the amount with which the suspended matter combines, then *alumina* will have to precipitate *alone*, and it does this only with a pH *near* 7.3, hence at high or low pH values, any *excess* of alum used will remain in solution and

impart a taste. As a rule, flocs produced with alum do not settle radiply or completely enough to allow a plant to be operated without filters.

Iron Sulphate—$FeSO_4$ $7H_2O$—will not form any floc at pH values below 6.6; between 6.6 and 8 it forms a very poor floc, but as the pH rises, the character of the floc formed improves steadily, and at 10 and above it forms a better settling floc than alum. With pH values *above* 8 no appreciable amount of iron remains in solution, even when it is used in excess.

When flocs are produced with iron sulphate and with pH values *below* 10, filters should be used because the floc does not settle rapidly or completely,—but with pH values of 10 or above, a floc may be obtained with iron sulphate which settles so readily that plants may be operated without filters. With properly designed plants only 1 p.p.m. or less of original turbidity or of floc will remain floating.

According to the writer's experience, plants to be operated without filters *should be limited* to the following principles of design and operation:

Treat the water with an accurately adjusted, maximum dosage of lime (see Method 8 below), use iron sulphate as a coagulant, stir the mixture with a properly designed paddle wheel for 20 to 45 minutes in a large basin, then deliver it into a settling tank large enough to give the water an 8-hour detention period, and supplied with "over-and-under" baffles to *skim* the water three times. The resulting water is free of suspended matter—except perhaps some freshly formed calcium carbonate—free from temporary hardness, and free from bacteria so that, in general, it does not require treatment with chlorine. The plants should be so designed that filters may be added when desired.

6. QUANTITY OF LIME, OR OF "WATER ALKALINITY" CONSUMED BY ALUM OR BY IRON SULPHATE.

One hundred pounds of filter alum react with—consume —25.2 pounds of *pure* quicklime; or 33.3 pounds of pure hydrated lime. 100 pounds of filter alum added to 1 million gallons react with—consume—as much of the alkalinity in

the water as 0.216 cc. of N/20 HCl in the "Total Alkalinity" determination (see below). 100 pounds of iron sulphate consume 20.1 pounds of pure quicklime; or 26.6 pounds of pure hydrated lime. 100 pounds of iron sulphate added to 1 million gallons consume as much of the alkalinity in the water as 0.173 cc. of N/20 HCl in the "Total Alkalinity" determination.

NOTE: Lime is never quite *pure;* freshly burned quicklime may be 98% pure, but the purity of older samples may go as low as 85%. Hence the operator must expect to use correspondingly *more* than the above calculated amounts.

The amounts of filter alum or iron sulphate required to clarify waters range *usually* from a minimum of 100 pounds to a maximum of 1500 pounds per million gallons, smaller or larger amounts being used rarely.

Hence the amount of total alkalinity *consumed* by alum ranges from 0.216 to 3.24 cc. of N/20 HCl (used to *titrate* 100 cc. of this water), while with iron sulphate, the total alkalinity consumed ranges from 0.173 to 2.6 cc. Use of these figures will be made at the end of the next topic.

7. METHOD FOR MEASURING TOTAL ALKALINITY—OR ACID-CONSUMING POWER—OF A WATER.

As the pressure measured by a gauge on a compressed air tank does not indicate the amount of air required to bring it to this pressure, so the pH value—or degree of acidity—of a water does not indicate the quantity of acid or alkali which produces it. These quantities have to be measured in another way—as follows:

The amount of acid required to lower the pH value to 4 measures the *Total* Alkalinity of a water, and this is determined as follows (this procedure is also found in Standard Methods for Water and Sewage, Am. Pub. Health Ass'n, 370 Seventh Avenue, New York, page 33):

By means of a 100 cc. volumetric flask, measure out 100 cc. of a sample of water, being careful to fill it until the lower part of the meniscus is on a level with the *pouring* mark on the flask, then empty this sample carefully into a 300 cc. conical flask—which latter has been previously rinsed with a little distilled water. Add one or two drops of methyl orange indicator solution. Fill a burette with

twentieth-normal hydrochloric acid by manipulating as described under Topic 2 above. Then allow this acid to "drop" into the water sample while the latter is constantly shaken with a *rotary* motion; stop as soon as a drop—after shaking—has imparted the proper tint to the whole liquid. For comparison, put into another such flask just as much *distilled* water and *just* as many drops of methyl orange as was used in the water sample above, and then blow the *breath* through this liquid by means of a glass tube; the tint which this mixture shows is the proper end point for the above addition of acid to the water sample.

Record the number of cc. of N/20 acid thus required for the above water sample.

Repeat the trial until two results agree within 0.2 cc. The total alkalinity of waters will usually be such as to consume from 4 to 14 cc. N/20 HCl per 100 cc. sample.

8. DETERMINATION OF EXACT AMOUNT OF LIME REQUIRED FOR REMOVAL OF TEMPORARY HARDNESS—MAXIMUM AMOUNT OF LIME ALLOWABLE IN TREATING A WATER.

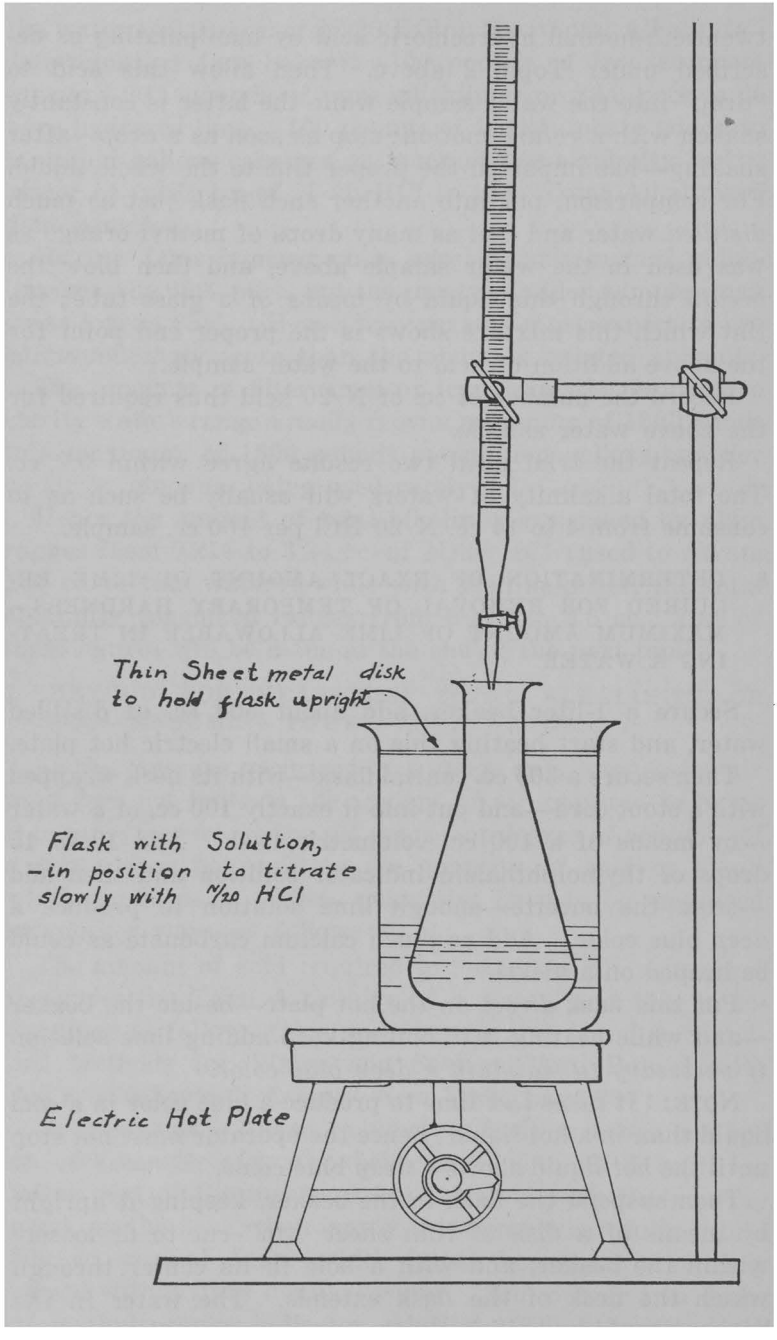
Secure a 1-liter beaker, add about 500 cc. of distilled water, and start heating this on a small electric hot plate.

Then secure a 300 cc. conical flask—with its neck wrapped with a stout cord—and put into it exactly 100 cc. of a water —by means of a 100 cc. volumetric flask. Add 10 to 15 drops of thymolphthalein indicator solution and then add —from the burette—enough lime solution to produce a *deep* blue color. Add as much calcium carbonate as could be heaped on a nickel.

Put this flask *direct* on the hot plate—beside the beaker —and while heating it to boiling keep adding lime solution *if necessary to maintain a deep blue color.*

NOTE: It takes less lime to produce a blue color in a cool liquid than in a hot liquid; hence the operator must not stop until the *hot* liquid shows a deep blue color.

Then suspend the flask in the beaker, keeping it upright by means of a disk of thin sheet "tin" cut to fit loosely within the beaker, and with a hole in its center through which the neck of the flask extends. The water in the beaker should be boiling gently.


Thin Sheet metal disk to hold flask upright
Flask with Solution, in position to titrate slowly with N/20 HCl
Electric Hot Plate

When the solid has settled, place the acid bûrette over the mouth of the flask, and without disturbing the flask, allow the acid to drop into it *very slowly*—about 1 drop in 5 seconds.

The observer should now seat himself so that his eyes are on a level with the blue liquid—he should have his back to the window, and he should have a white background, say a sheet of paper behind the flask, against which he views the flask. Stop adding acid when the blue color has *barely faded* out; a faint blue should still be visible.

Read the burettes and put down the readings. To make certain that the proper end-point has been reached, shake the flask to stir its contents, replace it in the beaker and wait until the solids have settled again: the liquid should show a faint blue color.

If the color is too deep, add another drop or two of acid, and when the proper tint is obtained, read the acid burette to get its final reading.

If the color is too light, or if it is desired to check the result, add just enough lime solution (about 3 cc.) to make the mixture deep blue again, and then add acid slowly as before to the proper end point. Read both burettes again and record the readings.

With the value marked on the lime bottle, calculate the amount of acid that each quantity of lime corresponds to, and subtract from that the quantity of acid used to remove the color; the remainders should be the same for the two sets of readings.

This remainder is a measure of the maximum amount of lime to be added to the water. It may be converted to other expressions as follows:

(a) multiply above remainder by 116.5; this gives the number of pounds of pure quicklime to be used per million gallons.

(b) multiply above remainder by 154; this gives the number of pounds of pure hydrated lime to be used per million gallons.

9. TO FEED LIME ACCURATELY IN A PLANT.

Hydrated lime can be fed by a dry feed machine. Quicklime must be slacked, and then fed by a machine which keeps the *slurry* well mixed, and which measures the flow accurately. *Wet feed* machines are easily tested by collecting some of the outflowing slurry. Dry feed machines also can be checked by using a tin can to catch the lime as it drops off the feed plate, and weighing it. If it is intended to feed 1000 pounds per million gallons flow per day, then the amount fed per minute is 0.694 pounds—and the flow per minute is 694 gallons.

The water flow must either be constant, or there must be some device *actuated* by the water flow which regulates the speed of the lime feed machine.

The mixtures should be thoroughly mixed—preferably in a deep tank with rotating paddles—for 30 to 45 minutes. Unless the mixture is thus stirred, there is danger that the precipitation of calcium carbonate will be incomplete, and then crystallization will occur later—in the water pipes—with disastrous results (called "after-crystallization").

If the water is to be softened, then care must be taken to avoid feeding essentially less than the "maximum dosage" because lesser amounts *increase* the danger of the above-mentioned phenomenon of "after-crystallization." The use of *less* than the maximum dosage of lime also does away with the germicidal effect of the "alkalinity," so that chlorine would have to be used.

Caution: Always test the treated water to ascertain whether or not it is being correctly treated with lime; to do this, take samples deep out of the stirring tank (with a bottle tied to a stick), and make the same test on this as on the raw water—as per Topic 8. Do not let a blue color shown by cool solutions mislead you.

The remainder obtained on testing a treated sample should correspond to a *deficiency* of lime in the water equal to some value between 1/2 cc. and zero. That is, a correctly treated water when tested as described in Article 8 above should require slightly less—up to ½ cc. less—of acid than corresponds to the lime used; but the difference should not be greater than this.

10. DETERMINATION OF AMOUNT OF LIME OR OF ACID REQUIRED TO CHANGE THE pH VALUE OF A WATER.

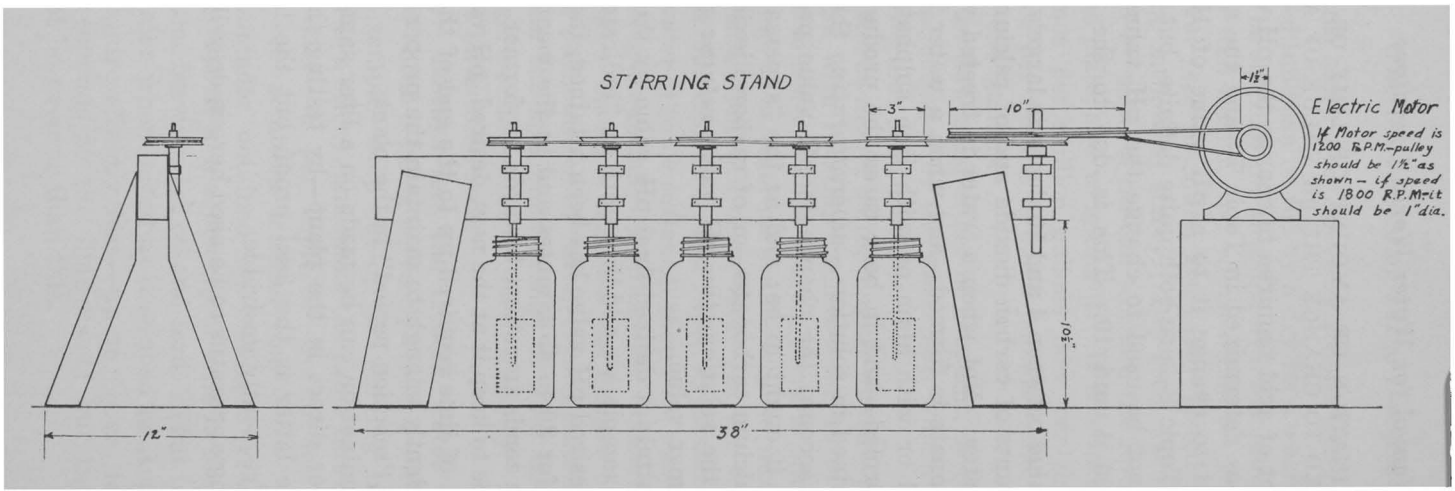
The amount of acid required to change the pH value of a water to 4—as determined in Topic 7—and the amount of lime required to change it to a pH value of 10—as determined in Topic 8—are both quite definite, but the same methods cannot be used to change the pH value to some value between 4 and 10. This is due to the following cause:

Any pH value between 4 and 10 depends largely upon the relative amounts of carbon dioxide and of calcium carbonate in the water. But when a water is treated with lime, calcium carbonate is formed—and when a water is treated with an acid or with alum or with iron sulphate, carbon dioxide is formed—and in both cases the product is temporarily retained in solution—*supersaturating* the latter—and on this account the change in pH value produced is greater than it ought to be; and as the "supersaturating" amount of calcium carbonate—or of carbon dioxide—gradually leaves the solution, the pH value *returns* partly toward its former value.

Hence to attain a desired final pH value by the addition of lime, for example, we add lime until an "indicator" shows us that the desired pH value has been attained, then we stir the solution for 30 to 45 minutes and in the meanwhile, as the pH value tends to return towards its former value, we add more lime to keep it at the new, desired, pH value. The total amount of lime required up to the end of the stirring period is evidently enough to maintain the proper pH value to the end of "reaction period" in the plant.

This determination can be made on a liter sample in the laboratory—or direct in the plant—by testing the treated sample. The latter is the *final* proof, but the laboratory test is also frequently desirable.

The stirring apparatus to be used here is described under "Apparatus."


STIRRING STAND
3"
10"
1½"
Electric Motor
If Motor speed is 1200 R.P.M.-pulley should be 1½" as shown - if speed is 1800 R.P.M. it should be 1" dia.
10½"
12"
38"

Put 1000 cc. of the water to be tested into each of three fruit jars (2 qt.), select three indicators so that the desired pH of the water is within the "color turning range" of one of them, while the second has a color turning pH range just slightly lower than that of the first, and the third slightly higher.

Add 20 to 25 drops of each of these indicators to one of the three different water samples respectively.

According to the pH value of the water, add either N/20 HCl or Standard Lime Solution from a burette to the sample containing the "middle pH indicator" until it turns color to indicate the desired pH value. Then add the *same amount* to the other two samples, and note whether or not they show the colors they should show. If not, add slightly more (or less?) equally to all until the desired pH appears to have been reached in all of them.

NOTE: This trial may be simplified by using only the one sample with the "middle pH value."

Place the samples under the stirrers, and start the stirrers. As the pH value returns toward its original value add more reagent from the burette to maintain the correct pH value, always adding the same amount to the three samples.

After half an hour, note the total number of cc. of standard solution required per 1 liter of water. The reagent required is almost always lime. To ascertain how much lime is required in pounds per million gallons, convert the number of cc. of lime used in this test to the number of cc. of tentieth-normal solution by multiplying with the value marked on the lime bottle, and then multiply the result further as follows:

For pure hydrated lime, multiply by 15.4,

For pure quicklime, multiply by 11.7.

The answer is in pounds for 1 million gallons.

NOTE: If the turbidity interferes with the observation of the color, add such a definite amount of a coagulant as will be more than enough to precipitate the turbidity, and also add just enough lime to correspond to this coagulant.

The amounts of coagulant and lime to be used and the manner of handling them are discussed in the next Topic.

CAUTION: Many waters have naturally a pH value between 8 and 9, a turbidity precipitable at pH 8 (or above), a total alkalinity requiring more than 10 cc. of N/20 HCl per 100 cc. sample; when such waters require only 500 lbs. or less of coagulant per million gallons, then they do not require any lime to adjust their pH values because the amount of alkalinity consumed by the coagulant will not reduce the pH appreciably. Hence the dosing of such waters seems not to require any particular care, and ignorant people draw the conclusion that all such dosing operations can be performed blindly.

But even though a water may—ordinarily—be thus easily treated, yet during flood periods the conditions are entirely different; the turbidity and hence the coagulant required is increased greatly, and hence, unless operators know how to *measure* the amounts required, they become helpless at the very time when the greatest care may be needed.

11. DETERMINATION OF THE AMOUNT OF ALUM OR OF IRON SULPHATE REQUIRED TO FLOC OUT THE SUSPENDED MATTER.

The proper amount of coagulant to use for a given turbidity is determined by direct trial—*first*, in the laboratory with samples of 1 liter, and again by adjusting the feed machines in the plant until proper coagulation is actually obtained.

For this determination, we employ the stirring stand described under "Apparatus"—which should operate at least five tests simultaneously.

Five 1000 cc. samples of the water are put into as many 2-qt. fruit jars or similar vessels. These are placed on the stirring stand, and the stirrers are started. The middle one has as much of the coagulant put into it as is *guessed* to be just *enough* for clarification. The amounts of coagulant put into the others should be more or less respectively so that the five samples present, from first to last, certain gradually increasing amounts. For example, if the amount

required is thought to be 500 pounds per million gallons, then the middle jar is given 5 cc. of either the *iron* or of the *alum* solution (see below) and the amounts put into the others may be such as to give the series, 3, 4, 5, 6, 7 cc.

Next, add to each jar the amount of lime that may be necessary to give each jar its proper pH value (as determined above) plus as much more as the coagulant requires. The latter amounts to the following: For this alum solution, as many cc. of your lime solution as are obtained by the following calculation: 2.16 divided by the value of 1 cc. written on your lime bottle and the result multiplied by 3, or 4, or 5, or as many cc. of alum solution as were put into a jar. For the iron solution, use 2.6 in place of the 2.16 above.

When this test is to be made for the case in which the water is given the maximum dosage of lime and is treated with iron sulphate, then an excess of lime *in this test* will do no harm—hence a fifth of a teaspoonful of hydrated or slacked lime merely need be put into each 1000 cc. sample, instead of lime solution.

After the mixture has been stirred for 30 minutes, the stirrer is stopped, and the mixtures are allowed to remain at rest for 1 to 3 hours. They are inspected from time to time to ascertain what is the *least* amount of coagulant which will floc out *all* of the suspended matter. To judge this properly, it should be remembered that the different kinds of flocs obtainable from different mixtures settle at greatly different rates—yet the liquid left *above* the floc should be perfectly clear.

For a plant operating without a filter, the floc should settle so readily as to leave the whole sample clear in 1 hour.

The solutions of coagulants to be used in this test are prepared as follows:

Iron salt solution: this may be prepared in either of the following two ways:

(a) Secure from a druggist about four ounces of tincture of iron chloride, U.S.P. This contains from 4.48 to 4.7 per cent of iron. Whenever this iron solution is to be used,

measure out with a graduated pipette or with a burette, 5.3 cc. of this tincture into a 100 cc. volumetric flask, fill this to the mark with distilled water, and mix the contents. This dilute solution will not keep and should be used only as long as it is without a sediment.

(b) Have a druggist weigh out accurately, 19.65 grams of crystals of potassium *iron* alum, put this into a 100 cc. volumetric flask, fill it to the mark with distilled water, close it with a stopper and shake it till the crystalls are dissolved and the solution is well mixed. This is the *stock* solution. Whenever some of it is to be used, take out 10 cc. accurately with a pipette, put this into a 100 cc. volumetric flask, fill this to the mark with distilled water, and mix the contents. This dilute solution, also, will not keep.

1 cc. of either one of the dilute solutions prepared as under (a) or (b) above, when added to 1,000 cc. of a water sample furnishes as much iron floc as 100 lbs. of iron sulphate crystals added to one million gallons of the water, and "consumes" as much of the alkalinity in the water sample as is indicated by 2.6 cc. of the N/20 HCl in the directions given in Article 7 above.

Alum solution: Secure from a druggist, 17.1 grams of crystals of *potash alum* accurately weighed and delivered into a 1000 cc. volumetric flask or stoppered cylinder. Fill this to the mark with distilled water, close it with a stopper and keep turning it over until the crystals have dissolved and the whole is well mixed. Then put the solution into a bottle to keep it. One cc. of this solution put into 1000 cc. of a water sample corresponds to 100 lbs. of *filter alum* put into one million gallons of water, and "consumes" as much of the alkalinity in the water as is indicated by 2.16 cc. of N/20 HCl in method 7 above.

12. DETERMINATION OF RESIDUAL CHLORINE.

When water or sewage effluents are treated with chlorine, the principal object is to obtain a water or effluent that is bacteriologically pure. For this purpose, so much chlorine must be used as to leave a definite amount of unused chlo-

rine in the water (called "residual chlorine"). To determine whether or not the chlorine is being applied in sufficient quantities o-tolodine reagent is used. The residual chlorine in the treatment of water should be from .1 to .2 parts per million, while in the case of sewage effluents the residual chlorine should be from 0.5 to .6 parts per million.

The solutions to be used in this test are prepared as given below.

O-tolodine Solution: put one gram of ortho-tolodine crystals into a liter flask, add 100 cc. of concentrated hydrochloric acid, then enough water to fill to the mark, and mix the contents.

Potassium Dichromate Solution: Weigh out accurately 0.25 grams of this salt, put it into a volumetric liter flask, add about 1 cc. of concentrated sulphuric acid, then fill the flask half full with distilled water, shake the contents until the crystals are dissolved, and finally fill the flask with distilled water to the mark,—and shake again to mix thoroughly.

Copper Sulphate Solution: Weigh out accurately 15 grams of this salt, put this into a volumetric liter flask, add about 10 cc. of concentrated sulphuric acid, then add water and proceed to make up the solution to a liter as with the dichromatic solution.

Procedure to determine the amount of residual chlorine: Mix 1 cc. of the ortho-tolidine solution with 100 cc. of the water sample in a Nessler tube, and allow the mixture to stand for at least 5 minutes.

Small amounts of chlorine are indicated by a yellow color, and larger amounts by an orange color. For a quantitative estimation, compare this color with those obtained by mixing the amounts of the above solutions stated in the table below—putting them into similar Nessler tubes, and filling these with distilled water up to the same volume as that of the sample.

In chlorinated drinking waters, the residual chlorine should be within the two following limits:

Solution of copper sulphate ($CuSO_4$)	Solution of potassium dichromate ($K_2Cr_2O_7$)	Chlorine in parts per million
1.8 cc.	10 cc.	0.1 ppm.
1.9 cc	20 cc.	0.2 ppm.

In chlorinated sewage effluents the residual chlorine should be within the following values:

Solution of copper sulphate ($CuSO_4$)	Solution of potassium dichromate ($K_2Cr_2O_7$)	Chlorine in parts per million
2.0 cc.	45.0 cc.	0.5 ppm.
1.9 cc. (see Note)	30.0 cc.	0.6 ppm.

NOTE: In this instance only 50 cc. of sewage are to be used, and this is to be diluted to 100 cc. with distilled water.

13. DIRECTIONS GIVEN BY THE TEXAS STATE HEALTH DEPARTMENT FOR COLLECTING AND SENDING WATER SAMPLES FOR BACTERIOLOGICAL ANALYSIS.

"Select a clear glass bottle of at least 6 oz. capacity, or better still, use sterile bottles and containers furnished free by the laboratory, prepared especially for this purpose. Boil bottle together with cork for fifteen minutes. The neck of the bottle and that portion of the cork which is inserted into the bottle should not come in contact with the hands which always harbor germs. When collecting water from a pump or faucet, allow the water to run about five minutes before taking sample. (When collecting from a lake or river, immerse the bottle at least one foot before removing stopper.) Then take the bottle by the bottom with one hand and remove the sterile cork with the other, holding the bottle under the stream of water until it fills. Then pour a little water out of the bottle in order to leave a small air space, and cork immediately, tying the cork down with twine so that it will not come out in transit. Do not seal the bottle with sealing wax or other such material. Send immediately by parcel post or prepaid express to a bacteriological laboratory. In warm weather, the sample should be constantly kept in ice, and in any case, it should reach the bacteriologist in as few hours as possible.

14. SUGGESTIONS FOR BACTERIOLOGICAL TESTS AND THEIR INTERPRETATION.

It is suggested that samples for bacteriological analysis be sent to a regular bacteriologist, with the request for him to proceed as directed in American Public Health Association Standard Methods. The report should state the total number of bacteria per cc. and also the total number of gas formers. The total number of bacteria, according to standard methods, should not exceed 100 per cc. No gas formers should be present. If the bacteriological examination shows the water to be bad, the operator should look for the cause. This may be from the following sources: (1) poor coagulation, (2) poor filtration, (3) not enough chlorine, (4) or if maximum lime procedure is used, and hence no chlorine, then the trouble may be due to a failure to dose properly with lime.

TESTS ON SEWAGE

15. DIRECTIONS FOR TAKING SEWAGE SAMPLES.

No specified "standard" or "fixed" procedure can be given as the variety of local conditions makes this practically impossible. However, the method outlined by the American Public Health Association states that samples of sewage effluents, industrial wastes, etc. should be taken over a period of at least 12 to 24 hours. Samples should be collected each hour, and in some cases every half hour. Sampling bottles should have a capacity of 150 cc. or more. Wide mouth bottles are preferable. A representative sample should at all times be obtained. This may necessitate the proportioning of volume of samples to flow. The *composite* sample (combined hourly samples) should not exceed 4 liters (1 gal.). In warm weather, the samples should be kept in ice.

16. DETERMINATION OF RELATIVE STABILITY OF SEWAGE EFFLUENTS.

This test is one which indicates the time required for the depletion of the available oxygen in a sample under con-

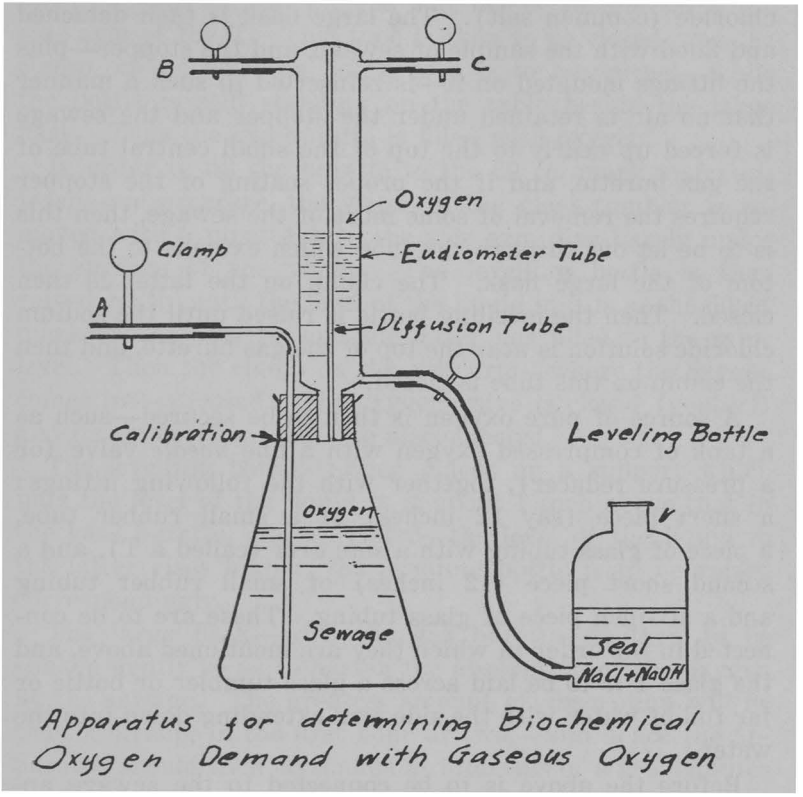
trolled conditions. The test depends upon the reaction (decolorization) of methylene blue indicator. A sample of 150 cc. is used, in a glass stoppered bottle of approximately 150 cc., or any other glass bottle of such volume that can be properly corked. Add exactly 0.4 cc. of methylene blue solution (see below) and incubate at 20°C. or keep in a room where the temperature remains fairly constant. Observe twice each day until decolorization occurs. Relative stability is obtained from the accompanying table (Taken from Standard Methods of Water Analysis):

Time in days for decolorization	Relative Stability in percent.
0.5	11
1.0	21
1.5	30
2.0	37
2.5	44
3	50
4	60
5	68
6	75
7	80
8	84
9	87
10	90
11	92
12	94
13	95
14	96
16	97
18	98
20	99

Methylene blue solution is made by dissolving 0.5 gm. of the double zinc salt or commercial variety in water and diluting to 1 liter.

17. DETERMINATION OF BIOCHEMICAL OXYGEN DEMAND BY SIERP'S METHOD.

The biochemical oxygen demand (B.O.D.) of a sewage is the oxygen in parts per million required during stabilization of its organic matter by aerobic bacteria, and is determined by the method of Sierp, *Ind. and Eng. Chem., 20,* 247 (1928).



Apparatus for determining Biochemical Oxygen Demand with Gaseous Oxygen

The apparatus consists of a 500 cc. flask fitted with a 60 cc. gas burette with two side arms at the top and one near the bottom. The side arms are provided with rubber tubing and clamps. The lower side arm is connected to a leveling bulb. A small tube extends to the bottom of the flask, and is also fitted with rubber tubing and clamp.

The apparatus should be thoroughly cleaned and dried after each determination.

In making a determination, the apparatus is assembled as shown in the accompanying figure, with all clamps open. Then the levelling bottle is filled with a solution prepared by dissolving 10 grams of sodium hydroxide in 100 cc. of distilled water, and saturating the mixture with sodium

chloride (common salt). The large flask is then detached and filled with the sample of sewage, and the stopper—plus the fittings mounted on it—is reinserted in such a manner that no air is retained under the stopper and the sewage is forced up nearly to the top of the small central tube of the gas burette, and if the proper seating of the stopper requires the removal of some more of the sewage, then this is to be let out through the tube which extends to the bottom of the large flask. The clamp on the latter is then closed. Then the levelling bottle is raised until the sodium chloride solution is *near* the top of the gas burette, and then the clamp on this tube is closed.

A source of pure oxygen is then to be secured—such as a tank of compressed oxygen with a fine *needle* valve (or a pressure reducer), together with the following fittings: a short piece (say 12 inches) of a small rubber tube, a piece of glass tubing with a *side arm* (called a T), and a second short piece (12 inches) of small rubber tubing and a six-inch piece of glass tubing. These are to be connected in the order in which they are mentioned above, and the glass T is to be laid across a glass tumbler or bottle or jar full of water with the side arm extending down into the water.

Before the above is to be connected to the sewage apparatus, the needle valve should be opened to obtain a gentle stream of oxygen. (NOTE: A needle valve should never be handled with pliers; it should always be operated gently with bare hands.) To ascertain when the valve is open sufficiently, the end of the 6-inch glass tube is to be covered with a finger, and then a gentle stream of gas should bubble through the water from the side arm.

Then this glass tube is to be connected to one of the side arms at the top of the gas burette, and the stream of oxygen is to be allowed to pass across the top of the burette long enough to sweep out the air. Then the other side arm is to be closed, and the clamp on the tube which extends to the bottom of the large flask is to be opened to let out about 150 to 200 cc. of sewage; to do this, the whole apparatus

must be *tilted* so that the gas may not be forced out of the side arm of the T. This tube is then to be closed, and the clamp on the levelling bottle tube is to be opened—while the bottle is still standing on the table beside the large flask. Thus the gas burette is filled with oxygen.

In order to fill the burette to the 60 cc. mark *under atmospheric pressure,* the water in the glass tumbler is removed with a pipette until the side arm dips barely under the surface of the water. The levelling bottle is then raised gently until the level of the liquid in it is at the 60 cc. mark on the burette, and the latter has filled to the same level. Then the clamp on the side arm—where the oxygen comes in—is closed. The oxygen valve is closed (gently!) and its connecting tubes are disconnected.

The levelling bottle is then placed on a support which puts the level of the liquid in it about 1 inch above that in the gass burette, and as—later—the level of the liquid in the latter rises higher, the levelling bottle is to be raised correspondingly.

The large flask—with the gas burette—is then to be shaken gently so as to hasten the absorption of the oxygen by the sewage. The greatest amount of absorption will be that occurring in the first hour or two,—and hence the apparatus should then be shaken at intervals of a few minutes until absorption is no longer noticeable; then the levelling bottle is to be lowered until the liquid in it and in the gas burette are on the same level. The corresponding mark on the burette is to be noted, and recorded together with the exact time interval since the beginning.

Then the levelling bottle is to be replaced in its higher position. The apparatus is to be covered with an inverted cardboard box to shut out the light, and allowed to remain thus for 10 to 20 days—except to be shaken and the gas volume read at intervals of several hours during the first few days, and once a day after that. The apparatus should be kept in a room in which the temperature is near 20° C. or 68° F. A thermometer should be kept beside the ap-

paratus to indicate the temperature, and the latter should be recorded.

Readings of the liquid levels—as shown above—are to be recorded together with the exact number of hours from the beginning.

When the determination is terminated, the amount of sewage in the large flask is to be measured. To do this, put the levelling bottle down on the table, open the clamp on the tube which extends to the bottom of the large flask, and remove the stopper with what it carries.

Weigh the large flask with the sewage, using a small platform balance with a capacity of not over 1,000 grams and using *gram* weights.

Then empty the flask, wash and dry it, and weigh it again; the difference in these gram weights gives the amount of sewage operated on. This should be recorded with the above data.

If a barometer is accessible, or a U. S. Weather Observatory is nearby, then the barometric pressures acting during the period of the determination should be secured and recorded.

If these are inaccessible, a record should be made of the elevation—above sea level—of the laboratory in which the work is done.

The above data—of time, gas burette readings, weight of sewage, temperature, and barometric readings—should be directly reported to a chemist—without any recalculations.

The chemist should then make the following calculations:

(a) The differences between consecutive readings give the volumes of oxygen absorbed during the corresponding periods of time;

(b) Each of these is to be divided by the weight of the sewage, and multiplied by 1,000;

(c) The gas volumes obtained in (b) are to be reduced to 0°C. and 760 mm., and corrected for aqueous vapor tension;

(d) The results from (c) are to be divided by 1.429. The result expresses the oxygen absorbed in *parts* per *million parts of sewage.*

(e) Plot the results of (d) against the length of time from the beginning to the time of each observation.

This *plot* is the final result.

18. TOTAL SETTLEABLE SOLIDS.

This determination is made with an Imhoff Cone. Samples should be taken at definite intervals (usually one hour). A sample of either 500 cc. or 1000 cc. is used and from the volume settled out after an hour, the quantity of total settleable solids is obtained.

19. LIST OF APPARATUS REQUIRED.

There are a number of firms from whom this apparatus can be secured; only a few are referred to below, but this is merely to be definite and not for the purpose of directing purchasers specially to these firms. The firm addresses are:

Central Scientific Company, Chicago, Ill.
Arthur H. Thomas Company, Philadelphia, Pa.
Eastman Kodak Company, Rochester, N.Y.
LaMotte Chemical Products Company, Baltimore, Md.

The catalogue numbers given refer to Catalogue C of the Central Scientific Company. Cat. C—227.

pH Value Indicators. Secure the following indicators in dry form:
methyl orange—2 grams
brom-phenol blue—1 gram
methyl red—1 gram
brom-cresol purple—1 gram
brom thymol blue—1 gram
neutral red—1 gram
cresol red—1 gram
thymol blue— 1 gram
phenolthalein—2 grams
thymolphthalein—5 grams

Have a druggist weigh out the proper amounts to make 100 cc. of each—using the amounts of each stated in Article 4 above. Put up in 4-ounce bottles stoppered with a 1-hole rubber stopper into which a medicine dropper has been fitted.

13346	12 test tubes, 6-inch
13158	1 test tube rack—of wire
10496-F	2 10cc. graduated pipettes
5762	2 100cc. volumetric flasks
5762	1 1000cc. volumetric flask
5762	1 2000cc. volumetric flask
3660	1 1000cc. graduated cylinder, glass stoppered.
	6 tubes containing 1/10 gram-equiv. of hydrochloric acid, with funnel and "breaker" to make normal solutions. Pfaltz and Bauer, New York, 300 Pearl St.
	1/2 pound pure precipitated calcium carbonate, "Bakers Analyzed."
7570	1 6-inch diameter electric hot plate, preferably with 3 heats (may be purchased locally).
	3 beakers, Pyrex, 1000cc.
	6 flasks, conical or Erlenmeyer, of Pyrex glass, 300cc.
1912	2 burettes, 50cc., with glass stop cock.
2863	1 burette clamp for 2 burettes
13038-C	1 iron support, 24 inches high
	1 1-gal. bottle for liquid
	1 rubber stopper with 2 holes to fit bottle above
	1 3/4-gal. bottle
	1 rubber stopper with 2 holes to fit bottle above.
	Note: These bottles may be secured locally, and then the stoppers can be ordered: Cat. No. 11572. State larger and smaller *diameter* of each stopper in inches or mm.
2304	2 calcium chloride tubes, one bulb, 8 inches.
	1 lb. soda-lime, in lumps.
	5 sticks of glass tubing (soda glass) as used commonly in laboratories, length about 36 inches; inner diameter 5 mm.
	1 chemist's wash bottle, made of a 500cc. flask, a 2-hole rubber stopper, and the usual glass-tube fittings.
	3 ft. of small rubber tubing, inner diameter, 3/16 in., wall thickness 3/64 in.
3024	6 Nessler tubes—100cc.
	B.O.D. Apparatus for Sierp's Method: made by LaMotte Chemical Products Company.
6545	Cylinder of oxygen.
6549-A	Needle valve.
648	Small platform balance—Cenco trip scale
742-E	Block of metric brass weights, 1 gram to 500
14006-B	2 glass connecting tubes, T shape. Inner diameter, 5 mm.
	3 Imhoff tubes for determining settleable solids, obtainable from Arthur H. Thomas Company, Philadelphia, or Will Corporation, Rochester, N.Y.

5584 6 flasks, Erlenmeyer, of approximately 150cc. volume, glass stoppered, or glass stoppered bottles of this size.
Ortho-tolidine: purchase either 50 grams of crystals from Eastman Kodak Company, or 500cc. of solution from LaMotte Chemical Products Company.
1 stirring stand. See figure, page 24.

This is to be made to accommodate 5 Mason or Kerr fruit jars, 2-qt. size, and to rotate—simultaneously in all jars—a brass plate stirrer 2 inches wide and 4 inches high, at the rate of 3 revolutions per second (see figure).

This stirring stand can be made neatly by a mechanic at a cost between $25.00 and $30.00. Within this price range, it can be obtained—made to order—with aluminum pulleys, from W. F. Smith, mechanic, 3406 Wabash Street, Austin, Texas. The pulleys, etc., without the wooden horse may be obtained for $17.00 to $20.00. A suitable motor for driving the stirrers is the following—obtainable for about $15.00 delivered—Westinghouse, A. C., Type CAH, 1/20 H.P., Single Phase, 110 volts, 60 cycles, 1725 R.P.M. with a 1-inch diameter grooved pulley.

The stand may be made at very small cost as follows:

Secure 5 feet of brass rodding with any diameter from ¼ to ⅜ inch, and 2 feet of iron or brass pipe of such internal diameter that this rodding will just fit into it and freely rotate therein. Cut the former into 5 pieces of 1 foot each, and the latter into 5 pieces of 4½ inches each. Also cut from the remainder of the pipe, 5 pieces of ½" each. Secure enough sheet brass, about No. 20 gage, to make 5 pieces, 2x4 inches each.

Also, secure 9 inches of ½" steel shaft, and 3 inches of iron pipe in which this shaft just fits and turns freely. Cut this pipe into 2 pieces, ½ inch and 2½ inches long respectively—slip the ½" piece on the shaft to a point 3 inches from one end, and solder it on there.

Place the 5 pieces of pipe, ½" long, on their respective shafts near one end so as to leave 1 inch of the shaft projecting, and here solder these pieces to the shafts, using the solder on the side where the "1-inch ends" project.

Slip the 12-inch shafts through the 4½-inch pieces of tubing, and then solder each of the 2x4-inch pieces of sheet brass to one of these brass shafts at the end opposite to that at which the ½-inch piece of pipe was soldered, and so that the "overall" length of the stirrer is 13½ inches.

Then, at a wood-working mill, secure a piece of soft pine, 1x12x24 inches, *mark* the *center* and the *circumference* of one 10½-inch circle thereon, and also of six 3½" circles, and saw out—with a band saw—the disks corresponding to these circles. Then with any suitable machine, cut a groove ⅜" deep in the circumference edges of these 7 disks;—and at the *centers* of 5 of these 3½" disks, with a machine

drill, make holes *somewhat smaller* than the diameter of the brass rodding used, and press the 1-inch free ends of these shafts into these holes. The pulleys should fit tight on the shafts.

The 10½-inch disk and the remaining 3½-inch disk are to be machine-drilled, at their centers, to make holes slightly smaller than the 2½-inch length of pipe above; this piece is then to be pressed through both of them, and the 2 disks are then also to be fastened together with nails.

Next, the saw-buck frame shown in the illustration is to be made, and then the stirrers, etc., are to be fastened on the frame by means of metal straps and suitable screws—as shown.

Small round leather belting—or even stout fish line—may be used to drive the pulleys. The six pulleys of 3½" diameter should be in the same horizontal plane, and the belt connecting them should wind "in and out" from one pulley to the next—both ways.